

# ***U.S. Air Force***

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*Integrity - Service - Excellence*

## **Expanding the Digital Thread to Impact Total Ownership Cost**



**U.S. AIR FORCE**

**Dr. Ed Kraft**

**AEDC/CZ**

**Presented to the  
NIST MBE Summit  
December 18, 2013**



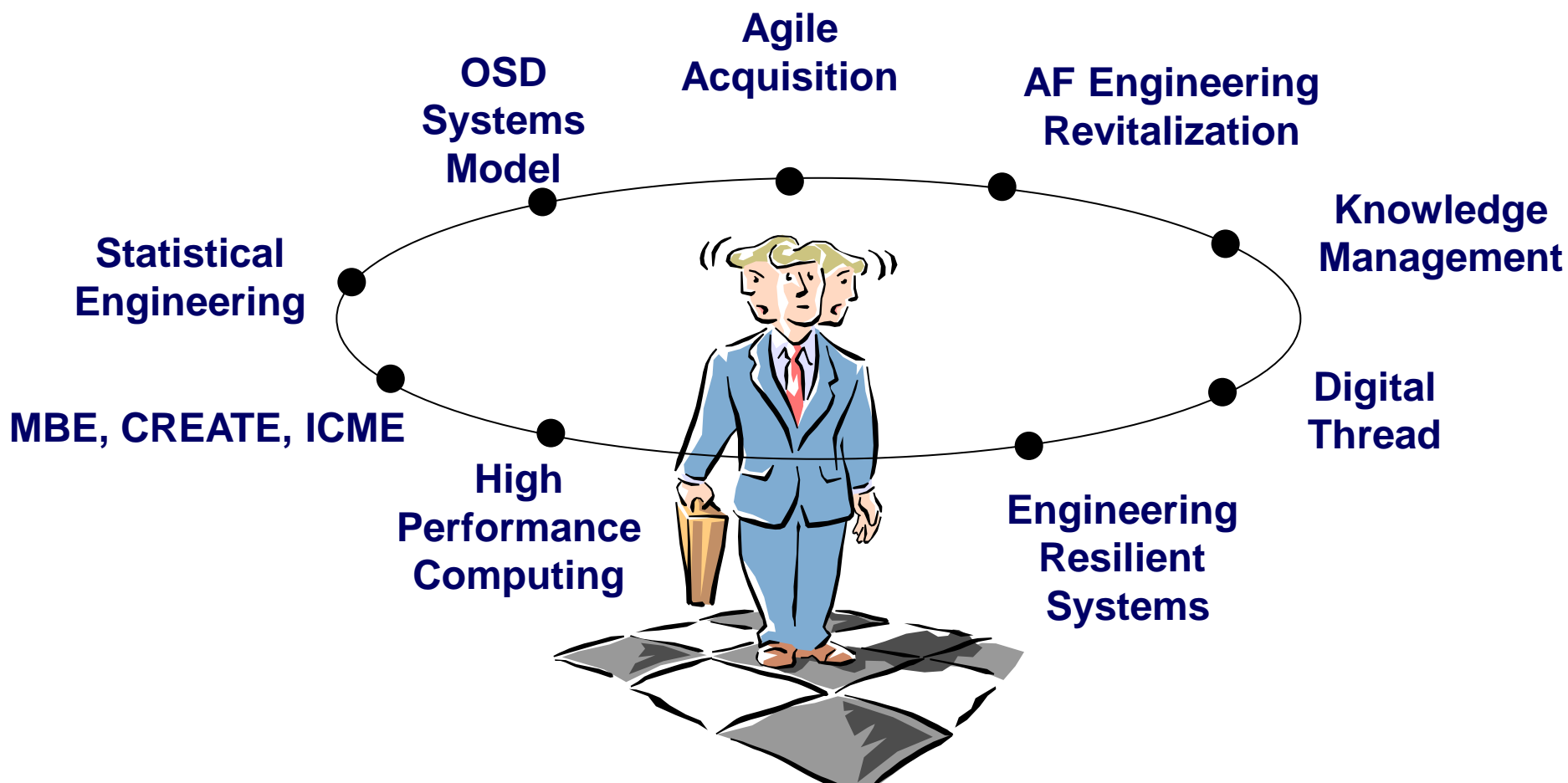
# Objectives

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- **Put the Digital Thread (DT) Concept into context with multiple ongoing activities**
- **Introduce the vision for the DT to impact the total life cycle of systems**
- **Highlight initial DT pilot efforts**



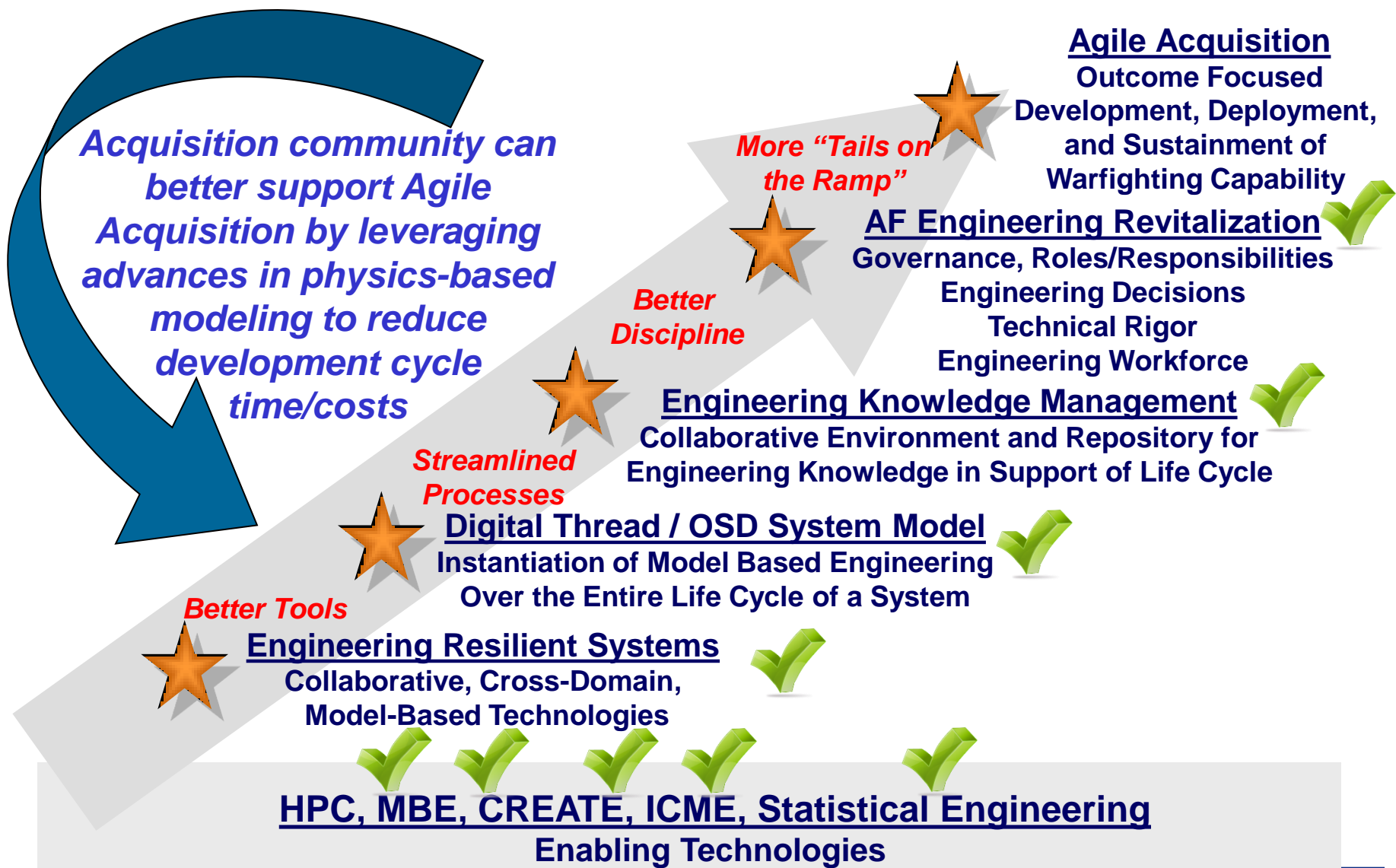
# What Are We Talking About?



**These are interdependent activities  
focused on the same outcome - improved  
acquisition and sustainment**



# Putting the Activities in Perspective

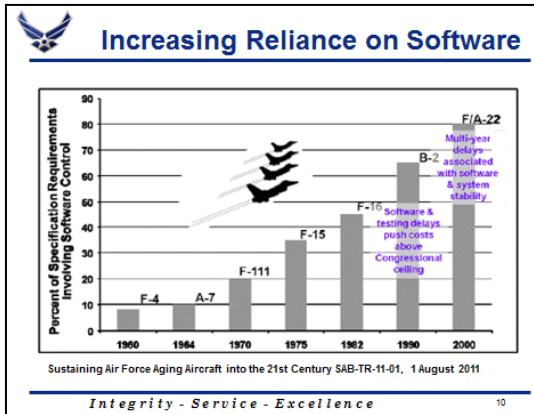
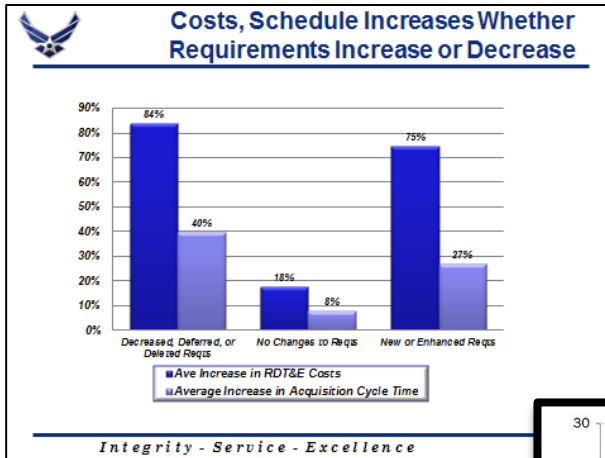




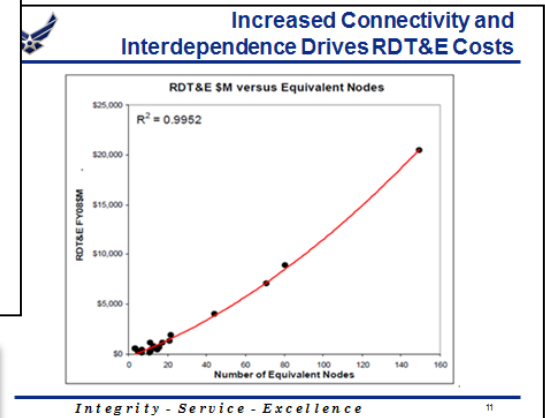
# Burning Platform

## Unsustainable Increases in Cycle Time/Costs

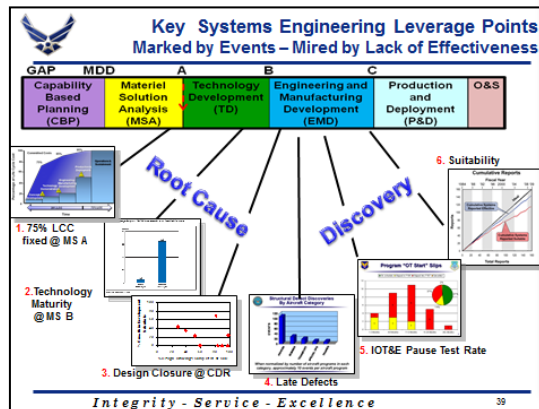
### Requirements



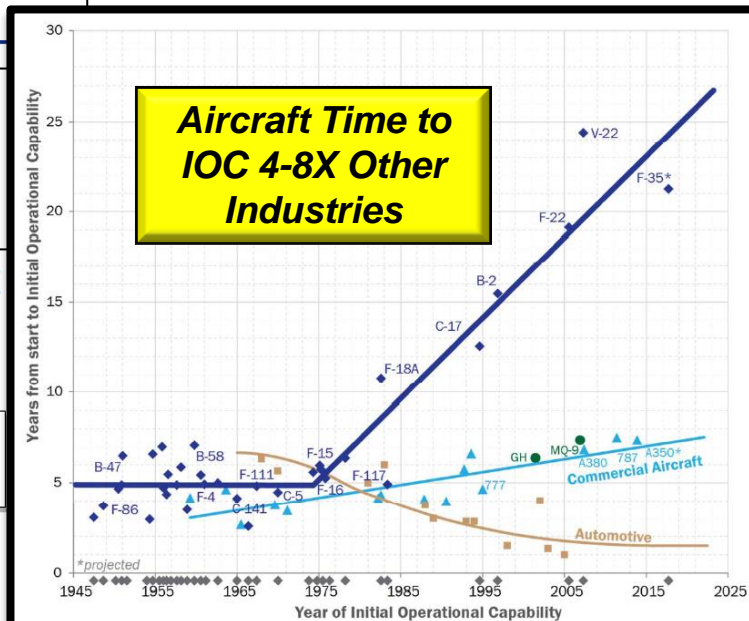
### Complexity



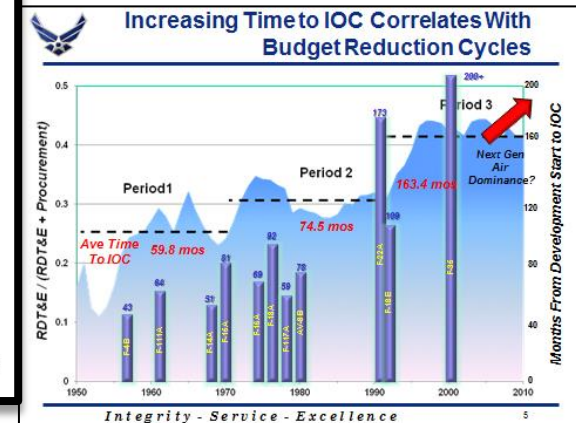
### Event Driven SE



**Aircraft Time to IOC 4-8X Other Industries**



### Capacity





# What is a Digital Thread? (Current Working Definition)

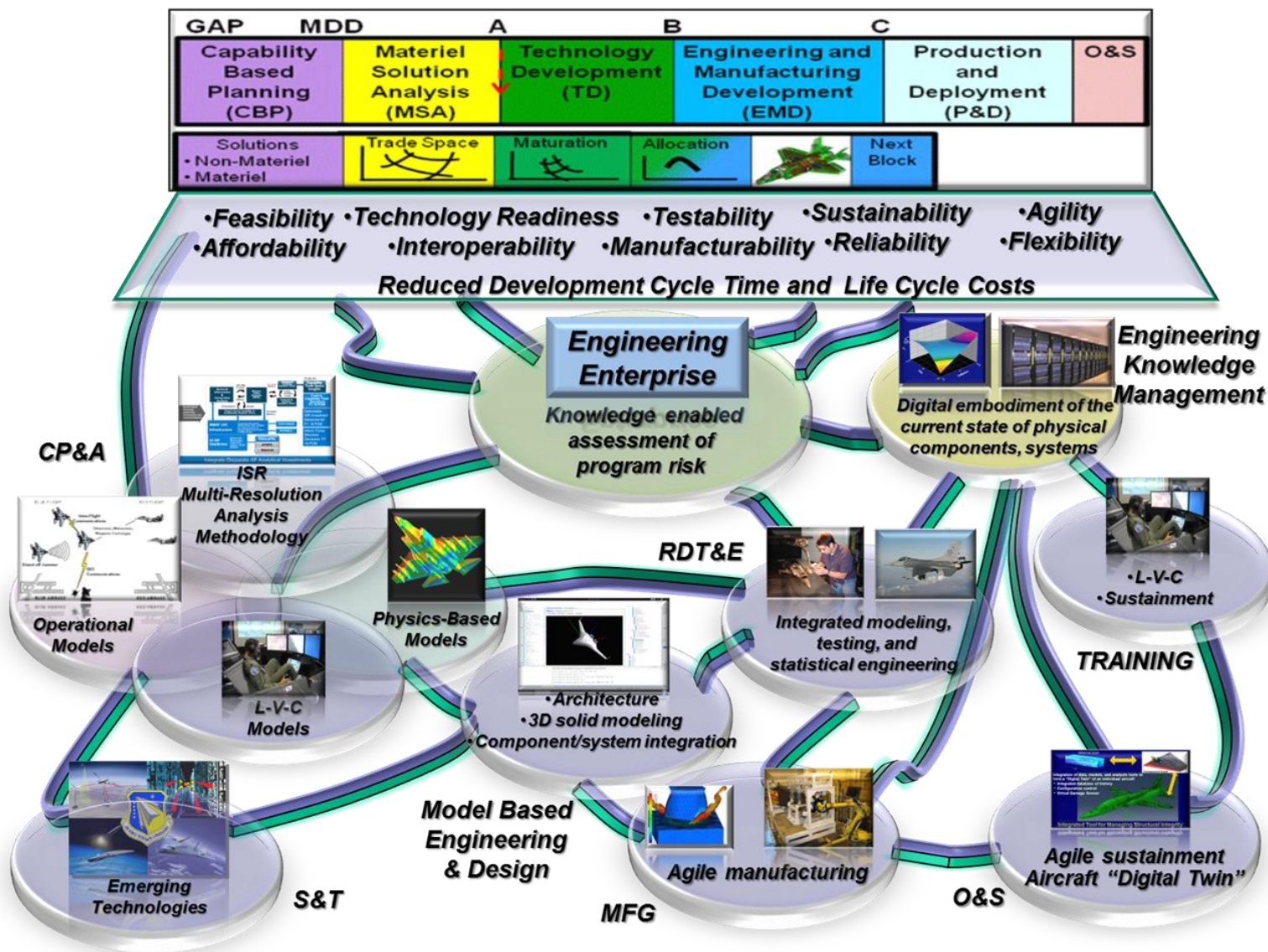
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*Digital Thread is the creation and use of **cross-domain, common digital surrogates** of a materiel system to allow dynamic, contemporaneous assessment of the system's current and future capabilities to inform decisions in the Capability Planning and Analysis, Preliminary Design, Detailed Design, Manufacturing, Testing, and Sustainment acquisition phases. The digital surrogate is a physics-based technical description of the weapon system resulting from the generation, management, and application of data, models, and information from authoritative sources across the system's life cycle.*

**The Digital Thread Puts Engineering  
Back Into Systems Engineering**

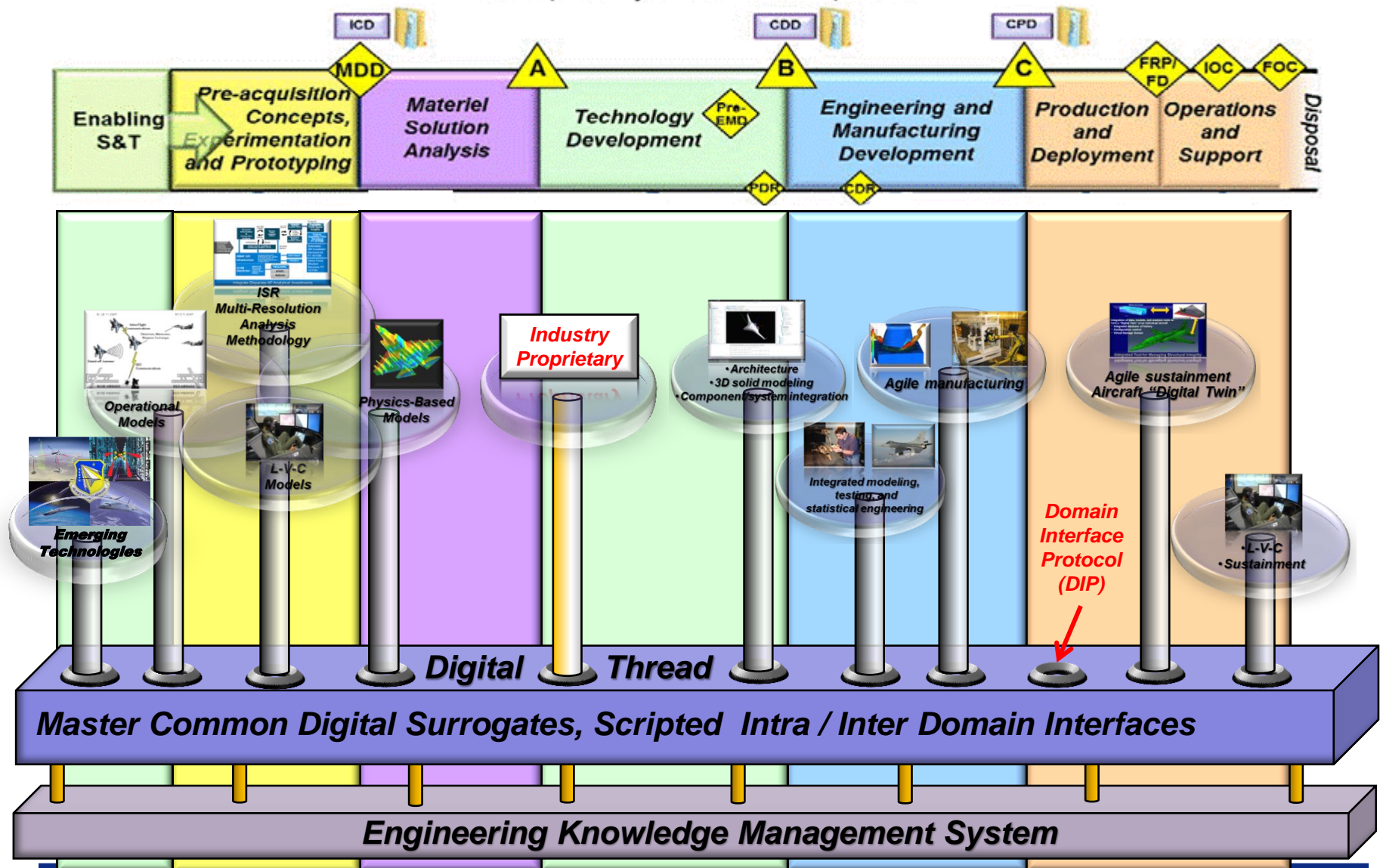


# Digital Thread OV-1



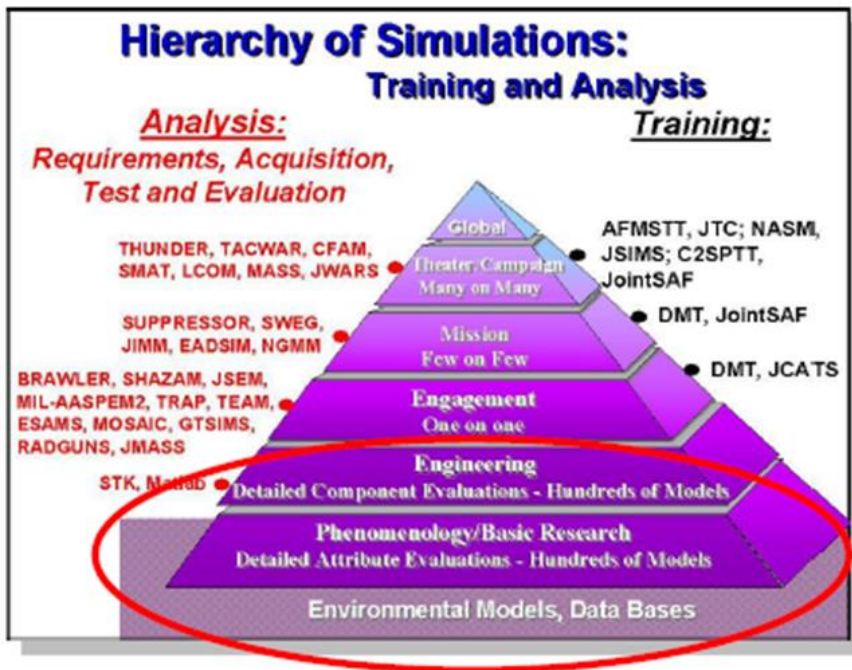


# Notional Digital Thread Architecture





# Why Now? What's Different?



**High-fidelity, physics-based models**  
**The untapped M&S capability**

- The Digital Thread provides the analytical framework for organizing output from high-fidelity, physics-based models across the entire life cycle
- Representation of results from multiple disparate physics-based models transferrable through digital surrogate response surfaces
- Rapid advances in High Performance Computing enable high-resolution simulations of complex systems practical and efficient

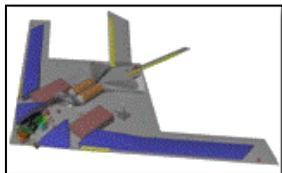
**We don't have to organize 100's of physics-base engineering models, just establish format and protocols for digital surrogate representations of the output from specialized models for each application domain**



# CREATE-AV

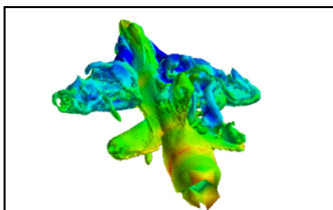
## (Computational Research Engineering Acquisition Tools Environment for Air Vehicles)

### DaVinci



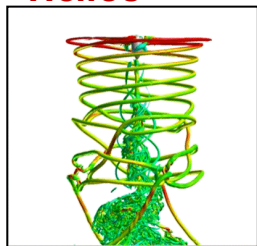
- Early engineering, design, and analysis

### Kestrel



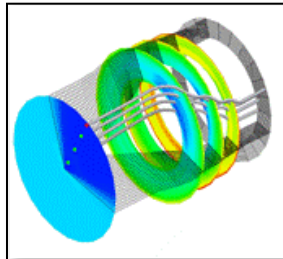
- High-fidelity, fixed wing flight system modeling

### Helios



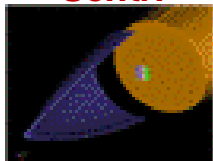
- High-fidelity, rotary wing flight system modeling

### Firebolt



- Propulsion module integrated into Kestrel and Helios

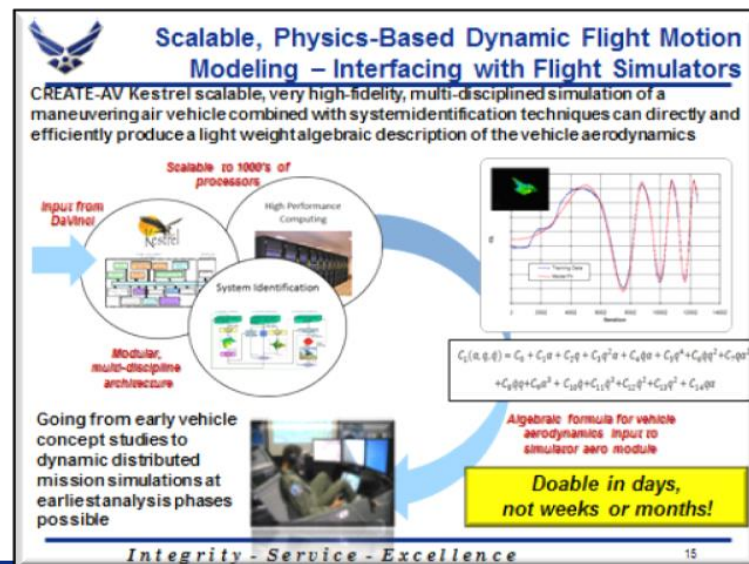
### Sentri



- CREATE-RF radio frequency modeling capability compatible with DaVinci

- A rapidly maturing physics-based flight system **modeling architecture** enabled by large scale computing
- **Scalable** to take advantage of HPC advances
- **Requirements** established by assessing 27 **acquisition and sustainment processes**
- Embedded capability to **efficiently generate digital surrogate response surfaces**

**Already over  
250 Users  
Across the  
DoD;  
Industry  
Investigating**





# The Digital Thread and the OSD System Model

## OSD System Model (Chapt 4 Defense Acquisition Guidebook)

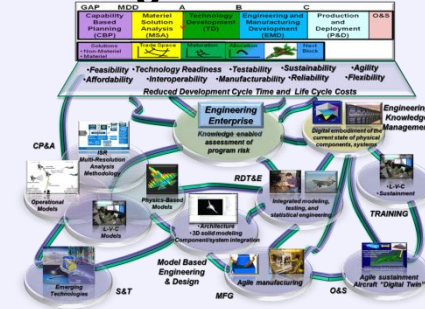
**ISSUE:** Current DoD acquisition activities do not develop, or maintain a single, integrated authority/artifact (aka system model) for a TBD subset of program data. Further, relevant data between acquisition activities is not adequately shared.

**VISION:** Use of a single model (aka system model) as an evolving, cohesive representation and unifying instantiation of the program under conceptualization, development, manufacture, and/or support: will increase efficiency of DoD system acquisition lifecycle activities, and increase confidence in decisions made regarding an acquisition program when the single (system) model (data) for that program is used.

**METHOD:** A system model will be instantiated by using artifacts and processes which already exist, or are already required by DoD acquisition policies, guidance, and best practices.

**OUTCOME:** The system model will be used by anyone performing activities related to the program as it evolves across the acquisition lifecycle, including but not limited to defining requirements, trading design aspects, designing, engineering, cost budgeting, staffing, manufacturing, fielding, training, sustaining, and disposing. The resultant system model will integrate program data into a complete description of the system.

## Digital Thread

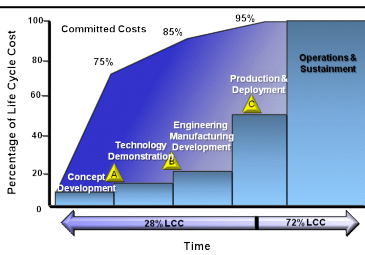
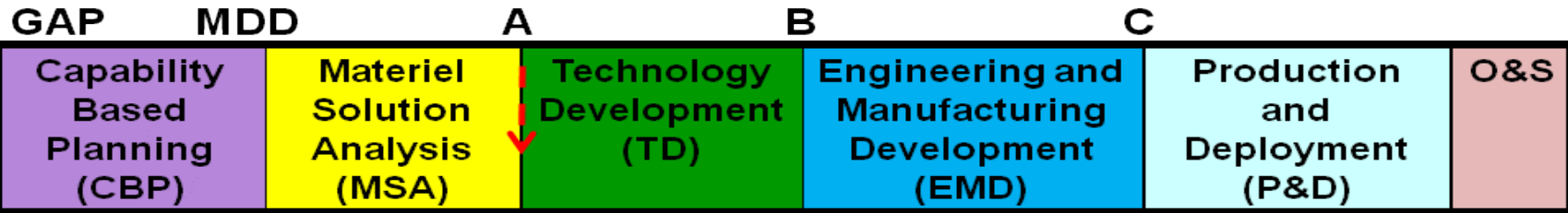


**Digital Thread is the creation and use of cross-domain, common digital surrogates of a materiel system to allow dynamic, contemporaneous assessment of the system's current and future capabilities to inform decisions in the Capability Planning and Analysis, Preliminary Design, Detailed Design, Manufacturing, Testing, Training, and Sustainment phases. The digital surrogate is a physics-based technical description of the weapon system resulting from the generation, management, and application of data, models, and information from authoritative sources across the system's life cycle.**

**The Digital Thread is the physics-based modeling instantiation of the OSD System Model designed to meet acquisition decision maker information needs**

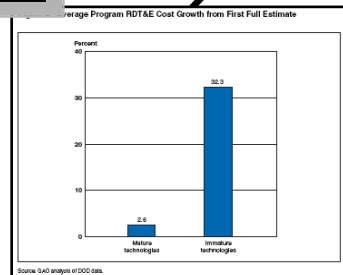


# Key Systems Engineering Leverage Points Marked by Events – Mired by Lack of Effectiveness

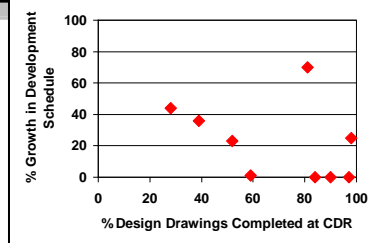


**1. 75% LCC fixed @ MS A**

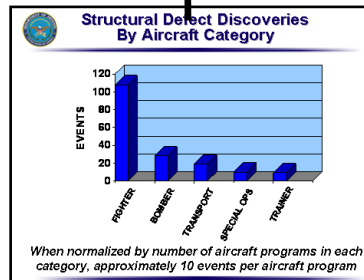
**2. Technology Maturity @ MS B**



**3. Design Closure @ CDR**

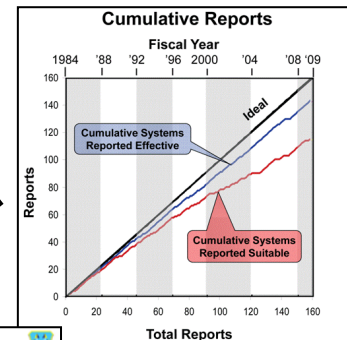


**4. Late Defects**

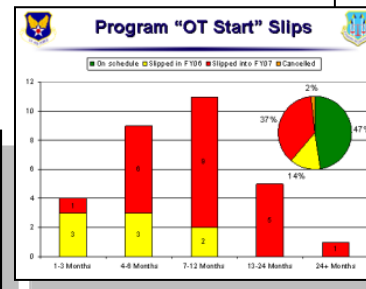


**Discovery**

**6. Suitability**

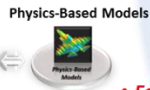


**5. IOT&E Pause Test Rate**



**S&T**

### ISR Multi-Resolution Analysis



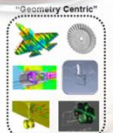
### Engagement Model

**CP&A**

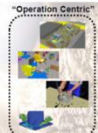
## Simulator



## Process Workflow



### 3D Parts Rendering



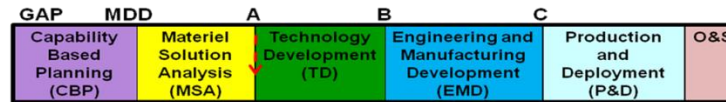
## Manufacturing Logistics

**MBE**

## Test & Evaluation



**Integrated modeling,  
testing, and  
statistical engineering**



**Root Cause**

**Discovery**

- **Technology Maturity Level**
- **Testability**

- Quantified Margins & Uncertainty
- Subsystem Integration
- Merged data and models in digital surrogate

- **Material Review Board Support**
- **Integrated Supply Base**
- **SLEP prognosis**

- *Rapid Response*
- *Repurposing for Changing Mission Threads*
- *Crisis Management*

- **Reduced O&S Costs Thru Optimum Maintenance, SLEP Planning**

- Operability
- Reliability
- Suitability

## Manufacturing

## Operations & Sustainment



Probabilistic Prognosis & Decisions



Inspections

 Models

1



Digital

### Training

- *L-V-C*
- *Sustainment*



# Creating a “Modeling Commons” for Capability Planning & Analysis – 1<sup>st</sup> Step to the Digital Thread

*Disparate skills, models, and communities*



**Campaign**

**Operation**

**Mission**

**Engagement Models**

## Operational Modeling

- Discrete Event Simulation, Agent Based Modeling
- < Real Time
- Scenario Visualization
- Event Engineering Models
- Table Look Ups



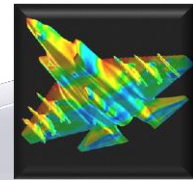
**ISR Multi-Resolution Analysis Methodology**

## ISR MRA

- ISR modeling
- System of Systems
- DOT\_PLF
- Networks
- Cyber interface

## Physics Modeling

- Discretized Physics
- >> Real Time
- Phenomena Visualization



**Physics-Based Models**

**“Modeling Commons”**  
Cross-domain model of a  
physically feasible, affordable,  
interoperable, and  
interdependent materiel solution



**Simulator Models**

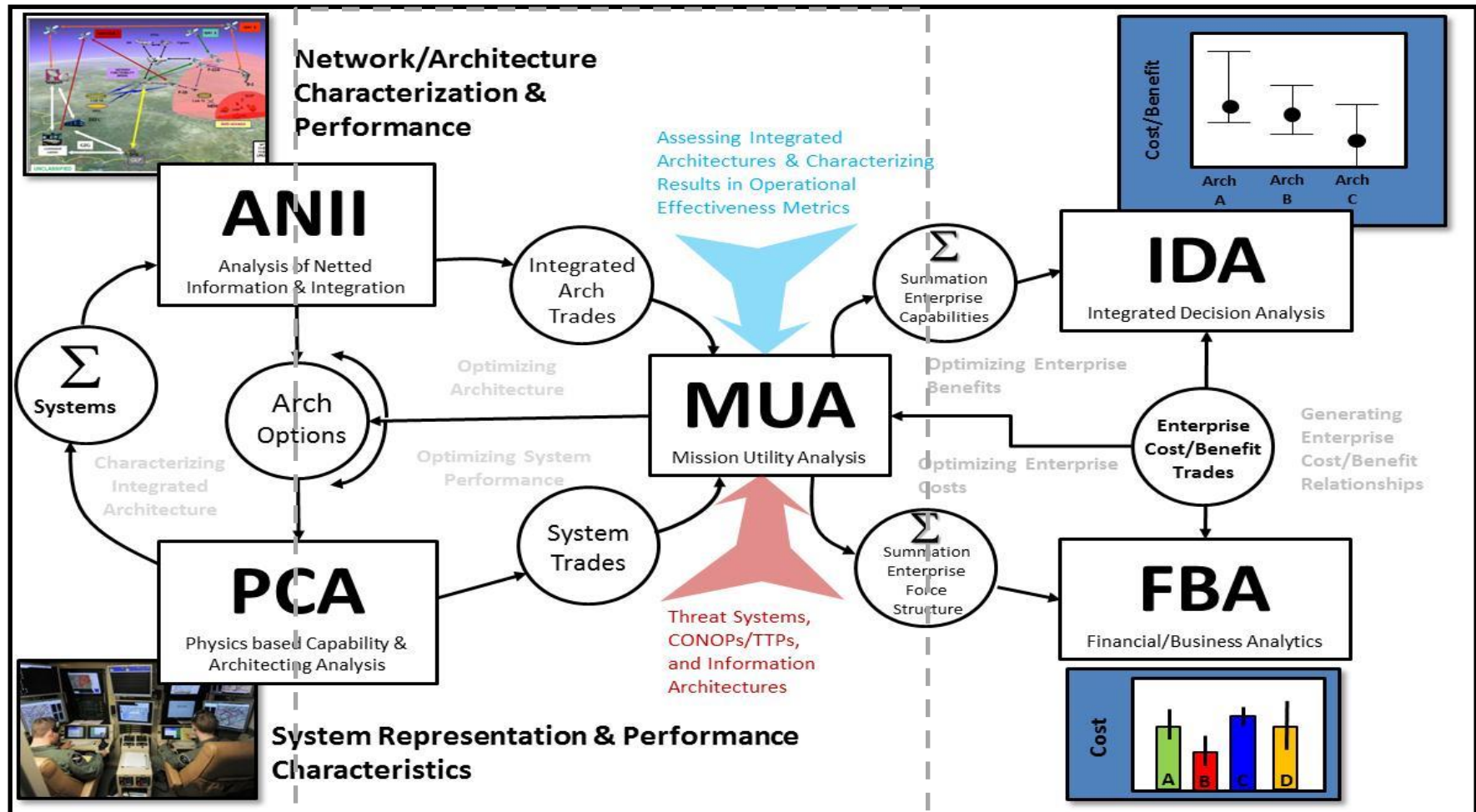
## LVC Simulator

- Discrete Event Simulation
- Real Time
- High Resolution Time–Space Visualization
- Event Engineering Models
- Table Look Ups



# ISR MRA Overview

## Framework for Integrating the DT into CP&A

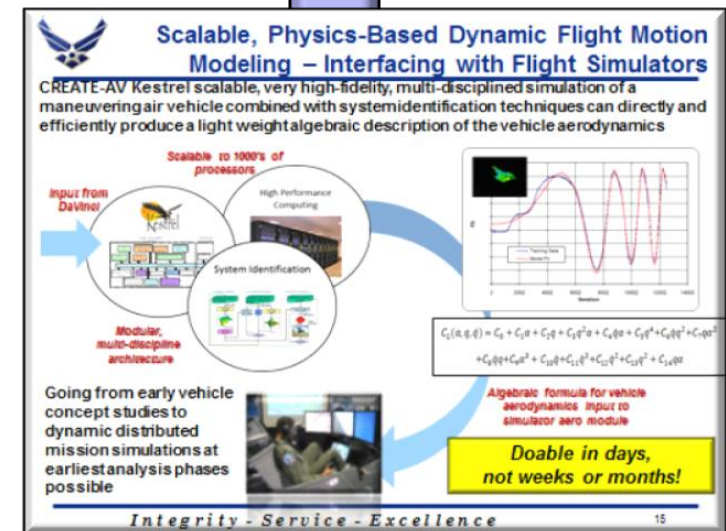
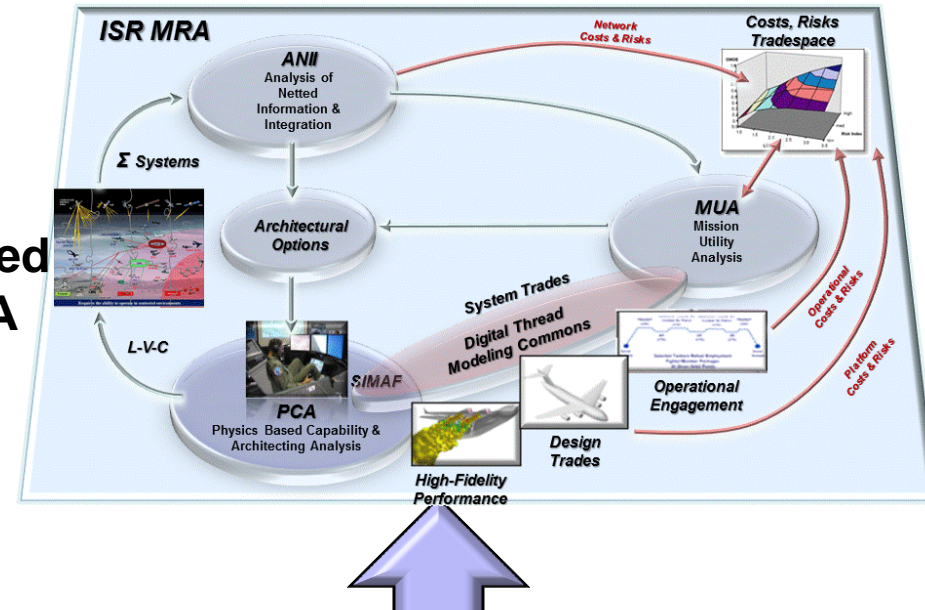




# Capability Planning & Analysis –Pilot Demo

## Connecting DT with the ISR MRA Capability

- Objective is to address feasibility, affordability, interoperability, and interdependency during the earliest analysis phase
- Introducing a high-fidelity physics based “fly out” model into SIMAF in the CP&A phase enables connectivity between materiel solutions, avionics architectures, and SoS interoperability
- Enables comparison of operational effectiveness/military value with incremental cost of requirement
- Opportunity to leverage activities in the ISR MRA development, HPCMP CREATE-AV development and funded activities with industry, and the OSD Engineering Resilient Systems initiative
- Real fountainhead for the development and application of the digital thread

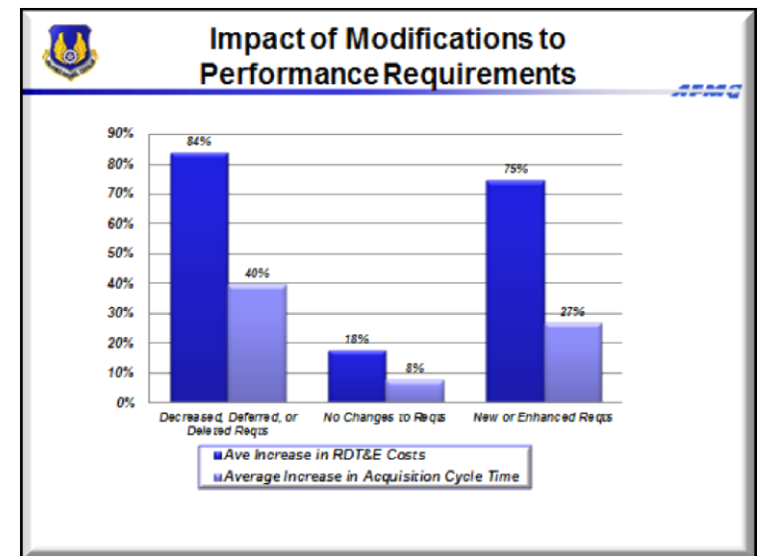
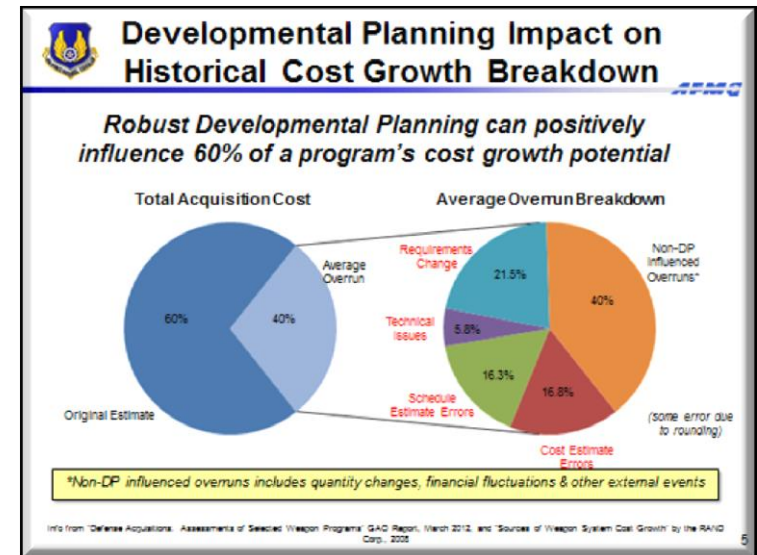
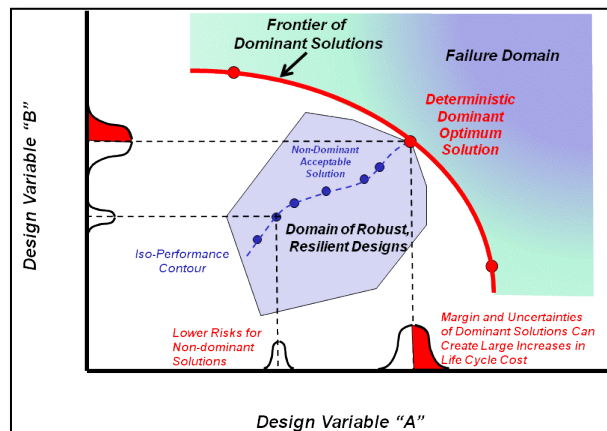




# Benefits of the Digital Thread support to Capability Planning and Analysis

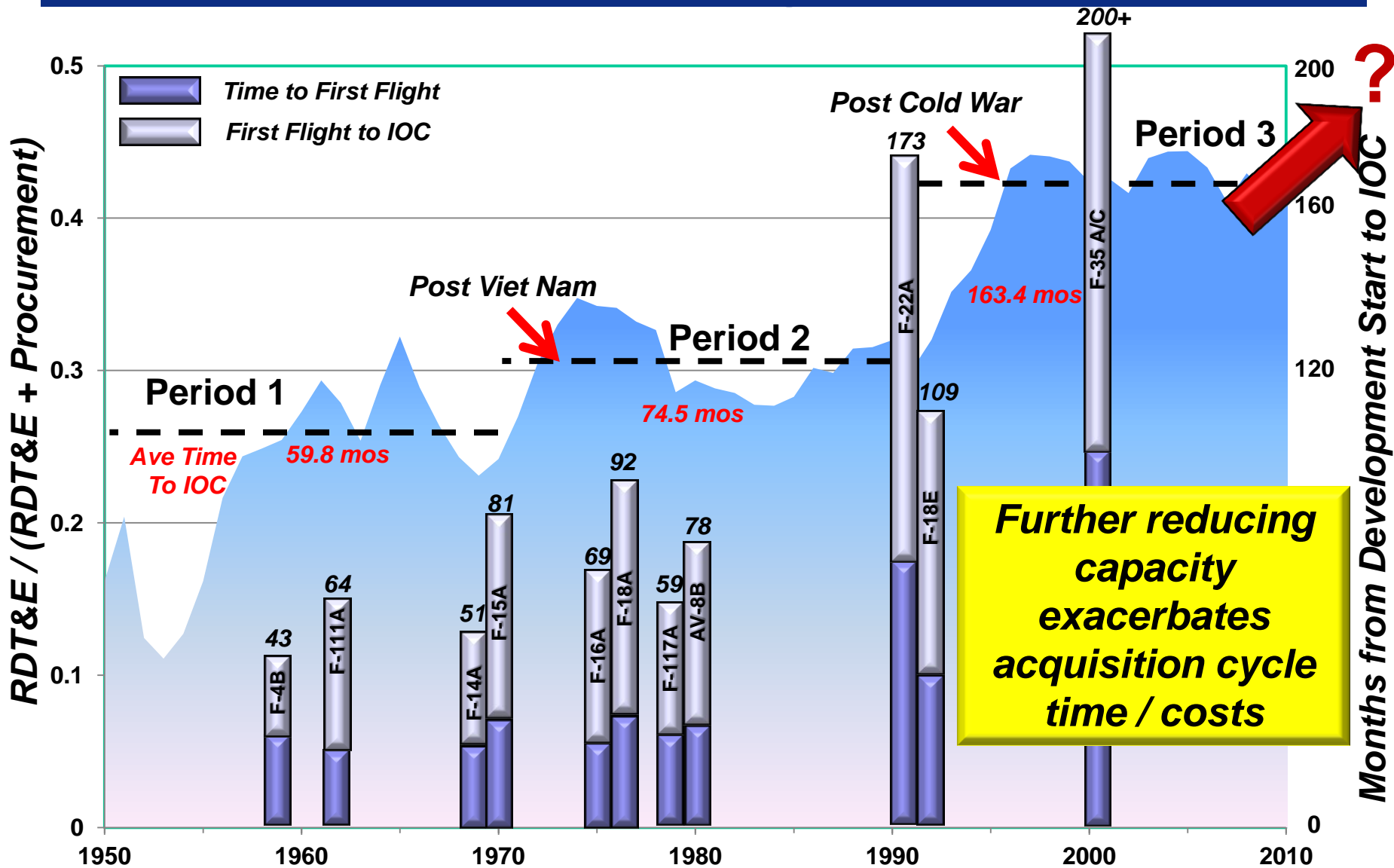
- A. Reduced cycle time between JCIDS, MDD, and MS A through more efficient and comprehensive analysis of requirements
- B. Reduced cycle time/costs between MS A and MS B as well as MS B to IOC through
  - technology maturation assessment
  - determination of resilient, realizable and affordable materiel solutions
  - reduced requirements volatility

**Resilient  
Design  
Space**





# Cost of RDT&E / Increasing Time to IOC Correlate with Budget Reduction Cycles

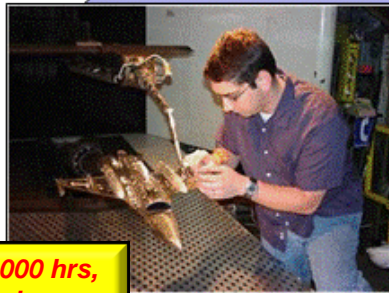




# Streamlining Developmental Testing at the Campaign Level (DT&E Overlays 80% of MS B to IOC Cycle Time)

**Common Thread  
System ID  
Techniques**

**"Fly the Mission"  
Ground Testing**



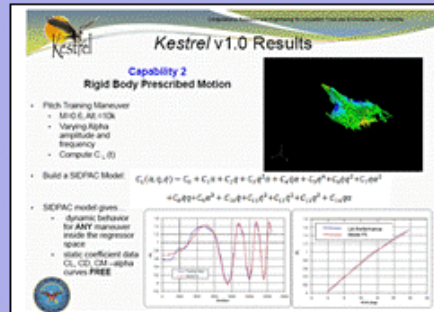
**Currently 22,000 hrs,  
4-yr campaign,  
2.5M data points for  
Stability & Control**



**Flight Testing**

**Currently 6-8000  
Sorties requiring  
6-8 years**

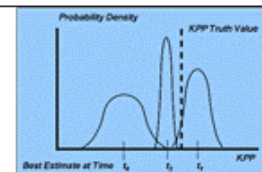
**Computational Science  
and Engineering Dynamic Trajectories**



**Physics Based  
Modeling**

**Digital Thread Enables  
Quantification of  
Uncertainty with Minimal  
Experimental Data**

**Estimation Theory  
Quantify Effectiveness of Testing**



Using Estimation Theory, variance reduction is proportional to the effectiveness of resources used and resources applied

$$p(t_{n+1}) = p(t_n) / (1 + p(t_n) u \Delta t), \quad u = \text{resource effectiveness}$$

$$\text{Or}$$

$$u(t) = (p(t_n) / p(t_{n+1}) - 1) / p(t_n) \Delta t$$

Which can be estimated used the SEMP, TEMP, and KPP values pre- and post-test

**Value of T&E**

**Digital Thread  
Surrogate Response  
Surface**

**DOE**

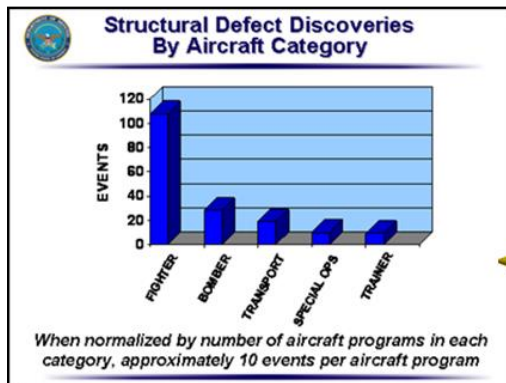
- Data Merge/Data Mine
- Response Surface Analysis
- Variance Reduction Strategy

Kraft, Edward M. "Integrating Computational Science and Engineering with Testing to Re-engineer the Aeronautical Development Process," AIAA Paper 2010-0139, January, 2010

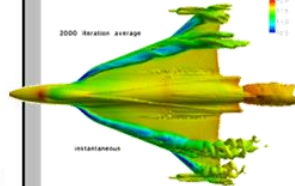


# Benefits of Digital Thread Support for RDT&E

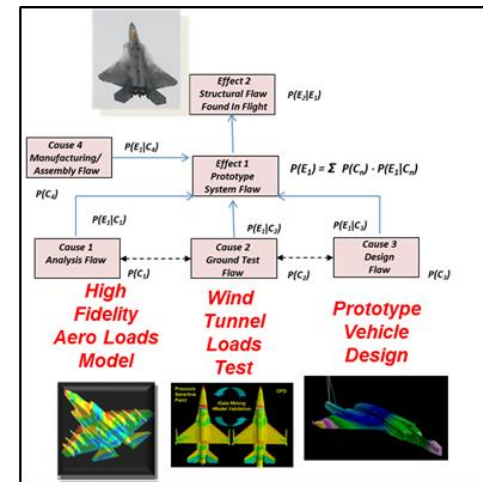
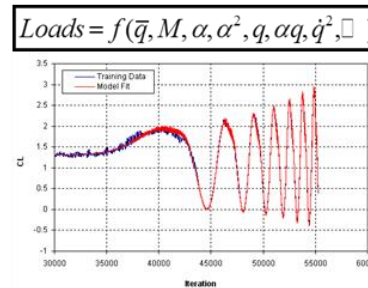
- Quantification of margins and uncertainties in system performance at critical decision points for more effective system engineering outcomes
- Integrates modeling and data into the digital surrogate response surface to mature the digital thread over the life cycle
- Requires addition of statistical engineering to quantify uncertainties
- Decreased cycle time through streamlined processes and minimum late defect discovery



**Kestrel + SID  
+ Proper Orthogonal  
Decomposition**



**Surrogate Digital Loads**



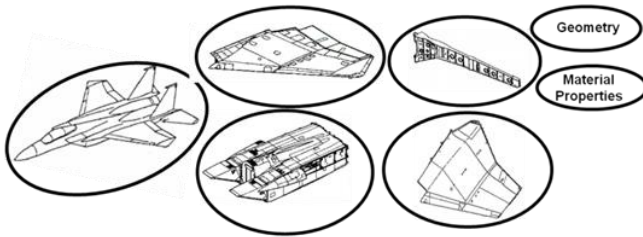
**Using the Digital Thread to overcome deficiencies in systems engineering, reductions in capacity, and late defects provides  
best opportunity to reduce time to IOC**



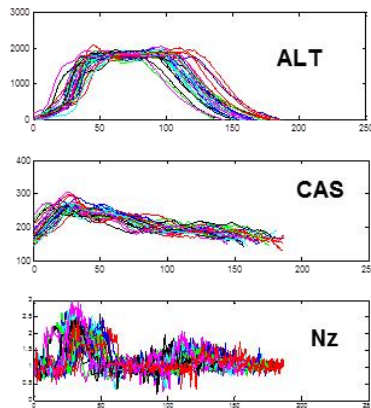
# Airframe Digital Twin

## Integrated Lifecycle Management Environment

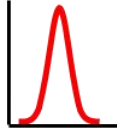
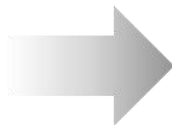
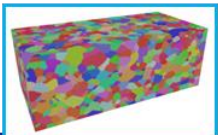
### Configuration Control



### Usage



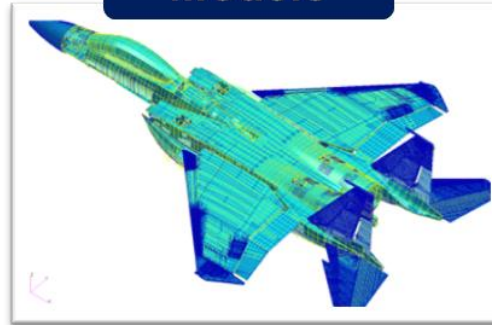
### Materials State Awareness



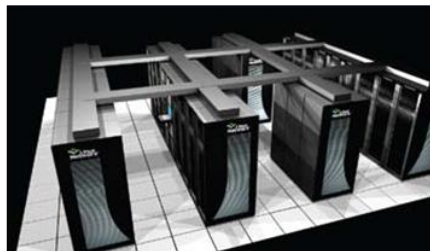
### Inspections



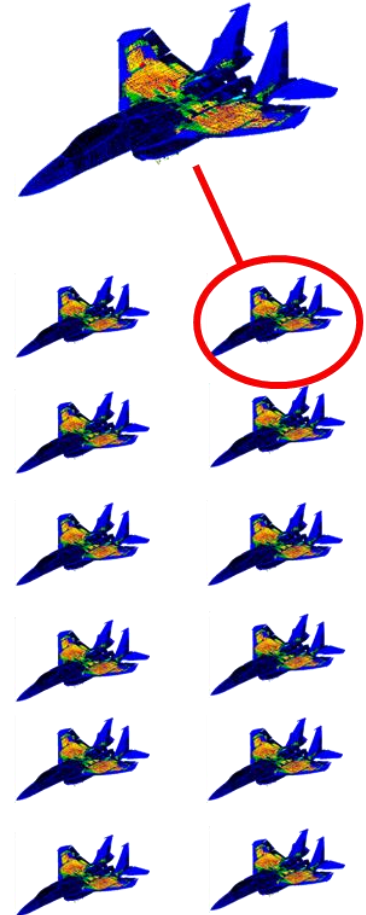
### Models



### Computation / Data



### Fleet & Tail # Lifecycle Management





## What We Need to Do

- Establish an integrated Enterprise vision for a “Digital Thread” supporting the acquisition and sustainment process
- Validate the payoff of the digital thread through the selected Pilot Studies
- Coordinate with the AF Engineering Revitalization and OSD System Model efforts to identify domain SOA and develop a governance process for the digital thread
- Develop the architecture for the digital thread to identify the Domain Interface Protocols, connectivity to a Knowledge Management System
- Work with industry to implement and institutionalize enhancements to acquisition and sustainment

***Leverage cross-functional, cross- organizational activities to weave a digital thread into a whole cloth approach to acquisition and sustainment of warfighting capabilities***



# Parting Thought

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**“It must be remembered that there is nothing more difficult to plan, more doubtful of success, nor more dangerous to manage than a new system. For the initiator has the enmity of all who would profit by the preservation of the old institution and merely lukewarm defenders in those who gain by the new ones. ”**

*Prince Niccolo Machiavelli*

